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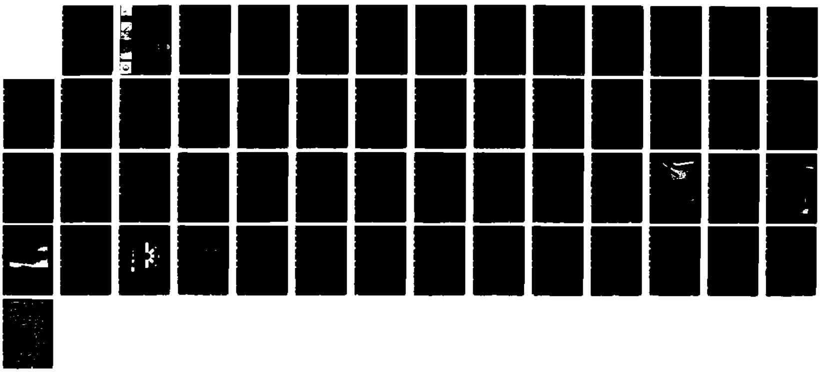

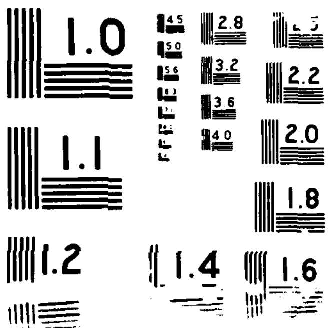
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WAVE CONDITIONS AT BARNEGAT INLET NEW JERSEY, 10 NOVEMBER 1984

by

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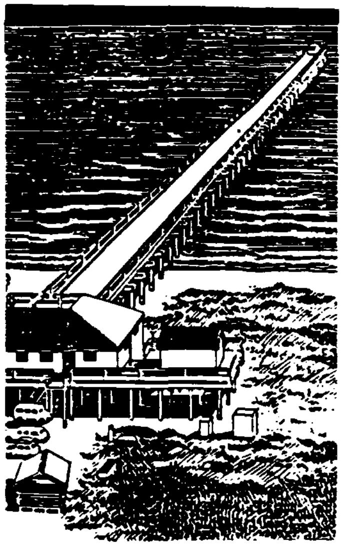

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Wave conditions at Barnegat Inlet, New Jersey, on 10 November 1984 are investigated because of a boating accident. The accident has resulted in a lawsuit against the US Army Corps of Engineers (Corps). Waves at Barnegat Inlet are hindcast with state-of-the-art numerical models including offshore wave growth and propagation and nearshore transformation. The waves of interest are swell waves originally generated well offshore in the north Atlantic Ocean. The waves are modified by the shallow bottom as they approach the coast. Tidal currents at the time of the accident and the effect on incoming waves are also estimated.

Wave measurement on 10 November 1984 from two sites are also investigated. A nearshore Corps wave buoy at Manasquan, New Jersey, provides important information relative to Barnegat Inlet. An offshore National Oceanic and Atmospheric Administration (NOAA) buoy

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19. ABSTRACT (Continued).

located southeast of Cape Cod, Massachusetts, is helpful in validating the hindcasts.

Wave conditions at Barnegat Inlet on 10 November 1984 are related to the general wave climate in the area by using the 20-year hindcast from the Corps Wave Information Studies. Significant wave heights and periods are higher/longer than average for the season, but neither height nor period represents a rare extreme event.

PREFACE

This report describes a study of wave conditions in the vicinity of Barnegat Inlet, New Jersey. The study was funded by the US Army Engineer District, Philadelphia (CENAP), because of a legal action filed against the US Army Corps of Engineers by the estates of two persons who perished in a boating accident at Barnegat Inlet. The study is focused on 10 November 1984, the day of the accident. The purpose of the study is to document wave conditions at the inlet at the time of the accident. Consideration is also given to currents through the inlet because currents are another natural force of significance at the time. The CENAP representatives monitoring the project were Mr. John Skarbek, Esq., and Mr. Jeffrey A Gebert. The US Department of Justice representative was Mr. Lawrence B. Brennan, Esq.

This report was prepared by Ms. Willie Ann Brown, Physicist, Dr. Charles E. Abel, Research Oceanographer, Dr. H. S. Chen, Hydraulic Engineer, Mr. William D. Corson, Research Physical Scientist, and Dr. Edward F. Thompson, under the direct supervision of Dr. Thompson, Chief, Coastal Oceanography Branch, and under general supervision of Mr. H. Lee Butler, Chief, Research Division, and Dr. James R. Houston, Chief, Coastal Engineering Research Center (CERC). The assistance of Dr. John M. Hubertz, Dr. Charles L. Vincent, Mrs. Rebecca M. Brooks, Mrs. Odia Winston, and Mr. Bruce A. Ebersole is acknowledged. The authors extend special recognition to Dr. Charles E. Abel, our colleague and co-author. He performed the offshore wave hindcasts for this study. Dr. Abel passed away on 19 April 1987.

COL Dwayne G. Lee, CE, was Commander and Director of CEWES during publication of this report. Dr. Robert W. Whalin was Technical Director.

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CONTENTS

WAVE CONDITIONS AT BARNEGAT INLET, NEW JERSEY
10 NOVEMBER 1984

PART I: INTRODUCTION

Background

1. At approximately 1230 Eastern Standard Time (EST) on 10 November 1984, a 23-ft cabin cruiser approached the entrance to Barnegat Inlet, New Jersey, from a northerly or northeasterly direction. As the boat was turning toward the west to move into the entrance channel between the jetties, it capsized. The approximate location of the capsizing is 150-300 ft east of the monument at the seaward end of the north jetty, in the vicinity of Points C and G shown in Figure 1. Two of the four occupants did not survive. Their estates have filed a lawsuit against the Corps of Engineers alleging improper design, construction, maintenance and/or repairs of the inlet.

2. Wave conditions at the time of the accident were estimated by several parties as listed in Table 1. Winds were 10 knots out of the south-southwest, as listed in the Marine Coastal Weather Log for Barnegat Inlet. The source of the damaging wave or waves and the way in which they were modified by the entrance are major unknown facts.

3. The presence of any inlet or entrance along the ocean coast causes characteristic changes to the bottom configuration and tidal currents in the local area relative to uninterrupted coasts. Typical bottom features of a tidal inlet are illustrated in Figure 2. The combination of shoals and currents at most entrances, particularly during ebb tide, creates more difficult navigation conditions in the entrance area than in the open ocean. Figure 3 shows the difficulty that can be experienced by a small boat passing into a jettied entrance. In this case, the boat was overtaken by a wave which lifted the stern and forced the bow beneath the wave in front of the boat. The photograph was taken at Indian River Inlet, Delaware.

4. The U.S. Army Waterways Experiment Station, Coastal Engineering Research Center (CERC), is a major center of coastal engineering expertise in the nation. CERC possesses state-of-the-art capabilities in both field data collection and analysis, laboratory modeling, and numerical modeling of

coastal phenomena. In the area of numerical modeling, CERC has the capability to use meteorological data (wind measurements and/or atmospheric pressure patterns) to predict wind-generated wave conditions over a body of water. If forecast meteorology is used as input to the models, the output consists of forecast wave conditions. If meteorology from past events is used as input, the output is commonly referred to as a "wave hindcast". Since past meteorological data are readily available for recent decades in the northern hemisphere, past wave events can be easily recreated with reasonable engineering accuracy.

Purpose and Scope

5. The purpose of this study is to document wave conditions and current effects at the entrance to Barnegat Inlet on the day of the accident. The study utilizes standard state-of-the-art numerical modeling techniques and available data.

6. The scope of the study was limited to accomodate a possible hearing date in Calendar Year 1987. The study was divided into three parts: (a) hindcast wave conditions and current modifications at Barnegat Inlet at the time of the accident; (b) compare the hindcast wave conditions with available data, including observations and buoy and near-shore gage measurements; (c) review long-term data sets for this and nearby areas and assess the severity of the event at the time of the accident relative to the wave climate at Barnegat Inlet.

PART II: HINDCAST WAVE CONDITIONS ON 10 NOVEMBER 1984

Offshore Waves

7. Estimates of wave conditions at Barnegat Inlet on 10 November were developed in a three-step numerical modeling process. The first step was to develop estimates of the wind-generated waves likely to affect Barnegat Inlet. It is important to note that waves of interest were not generated in the immediate vicinity of Barnegat because the local wind speeds were low. Thus the waves which caused the capsizing were generated in some distant reaches of the North Atlantic Ocean. Waves such as these which have propagated out of the generation area are referred to as swell. When the waves propagate over the continental shelf, they eventually become influenced by the shallow bottom. The second step of the numerical modeling process is to estimate the changes in wave height and direction induced by the shallow bottom, including the shoal areas in the vicinity of Barnegat Inlet. The third step is to estimate the intensity of the tidal currents emanating from the inlet and their effect on the waves.

8. The beginning point in hindcasting offshore waves is to consider the meteorology of the North Atlantic Ocean on the days surrounding the accident. Synoptic weather maps were obtained and studied. The maps are 3-hourly North American surface pressure charts and 6-hourly Northern Hemisphere surface charts produced by the National Weather Service (NWS). The Northern Hemisphere map corresponding most closely to the time of the accident is represented in Figure 4. The patterns shown are typical of the meteorological conditions preceding the accident, by which waves were generated and could propagate to Barnegat.

9. The weather maps show one atypical feature, a hurricane 1240 n miles offshore from Barnegat Inlet toward the southeast. Hurricane Klaus began as a tropical storm in the Caribbean Sea. It reached hurricane status at 1900 EST 8 November while centered 120 n miles northeast of Puerto Rico. Klaus maintained hurricane status until 1300 EST 12 November and followed a general north-easterly heading at forward speeds of 8-17 knots.

10. Another significant feature on the weather maps is a large high pressure center. The center was moving toward the east and, at the time of the accident (Figure 4), its high pressure center was located about 800 n miles northeast from Barnegat.

11. The two major weather features, Hurricane Klaus and the high pressure center, were moving on paths which eventually caused them to interact with each other. By 1300 EST, 9 November, the maps show evidence of isobars (lines of constant pressure) being crowded together between the two weather features. The crowding is evident in Figure 4. Crowded isobars indicate an intense pressure gradient in the area which would cause strong winds to blow. Contrary to intuition, the winds generally blow nearly parallel to the isobars because of Coriolis force and frictional effects along the earth's surface. Thus the crowded isobars between Klaus and the high pressure center would be expected to cause strong winds blowing over a relatively long fetch toward the southwest.

12. The weather conditions preceeding the accident indicate two potential sources of swell waves which could affect Barnegat Inlet. The sources are Hurricane Klaus and the area of crowded isobars between Klaus and the high pressure center. Both sources were investigated in this study. The hindcast interval selected extends from 1900 EST 8 November through 1300 EST 11 November 1984.

13. CERC currently has windfield models designed for use with synoptic-scale pressure fields and also for the tightly packed isobar patterns of a tropical storm, but not for a combination of both classes of pressure distributions. The strategy adopted for modeling these potential sources of onshore propagating waves is: (a) hindcast the winds and waves for hurricane Klaus, in isolation from the synoptic pressure systems; and (b) hindcast the winds for the larger scale pressure distribution, without detailed representation of the hurricane. Modeling Klaus in isolation is reasonable, provided that only long period hurricane generated swell is the feature of interest. These waves are essentially free surface waves, following (in deep water) great circle paths of propagation, unaffected by the local winds along their path. The coarser resolution synoptic hindcast (without small scale storms represented) is essentially the method used for the CERC Wave Information Studies (WIS) 20-year hindcast project referred to in subsequent sections of this report. This

method has been shown to give an excellent rendition of the synoptic distribution of wind waves, absent the extreme conditions associated with intense, small spatial scale events such as tropical storms and hurricanes.

14. Hurricane Klaus windfields were modeled with a moving-grid planetary boundary layer model (Cardone, et al., 1981). Input to this model comprises storm track positions, central pressure, radial scale of the closed isobar pressure pattern, forward speed of storm motion, and speed and direction of the ambient geostrophic winds ("steering flow"). Analysis of the NWS surface pressure charts led to selection of a 25-mile scaling radius and adoption of a constant central pressure of 971 mb. These parameters produce a quasi-steady state moving vortex wind-field with peak windspeed of 74 knots, consistent with Klaus being classified as a moderate hurricane. Initial estimates of storm position were obtained from the surface pressure charts. These positions were later revised according to a best fit track determined by the National Hurricane Center (Lawrence and Clark, 1985).

15. Final hindcast estimates of the winds were interpolated from the moving grid system onto a fixed wave hindcast grid covering the area between Hurricane Klaus and Barnegat Inlet. The grid is an expanded version of the WIS Phase II grid used in the Atlantic Ocean (Corson, et al. 1982). The grid was a 50x50 spherical orthogonal mesh of 30 nautical miles spatial resolution.

16. The wave hindcast was done with a general depth discrete spectral wave model. This model is currently being used for a 20-year hurricane hindcast for the WIS program. It includes parametric formulations of wind wave growth, nonlinear wave-wave interactions, spectral refraction, and swell dissipation. The wind data were supplied for input to the spectral wave model at 1-hr intervals for the 84 hour hindcast period.

17. Results of the computations were printed for the grid point nearest Barnegat at which WIS Phase II data have been summarized. The point, referred to as Station 27 (39.68 deg. N latitude, 73.72 deg. W longitude), is shown in Figure 5. The hindcast at Station 27 indicated swell waves with 14-sec period generated by Hurricane Klaus began arriving after 1900 EST 11 November. Since this is 31 hours after the accident, hurricane-generated swell does not appear to be a source of onshore wave energy affecting the accident.

18. The second phase of the wave hindcast utilized the WIS windfield model (Resio, et al., 1982). Digitized surface pressure data from a magnetic tape archive maintained by WIS supplied the input information to the Atlantic Phase I wind model. This large scale model grid has a resolution of 120 n miles and covers the entire North Atlantic Ocean north of 10 deg. N latitude. Winds computed on this grid were interpolated onto the 30 n mile resolution Phase II grid at 6-hour intervals through the 84-hour hindcast period. The interpolated wind data served as input to the general depth wave hindcast model. Local winds at the Barnegat weather station around the time of the accident were reported to be 10-14 knots from the SSW (245 deg. true, clockwise from north). Hindcast winds at WIS Station 27 (located approximately 20 n miles offshore) were 20 knots from 210 deg. true. The difference between the two is consistent with expectations of wind speed and direction differences between a point on land and a point on water at least 10 miles from land.

19. The wind and wave hindcasts for WIS Station 27 on 10 November 1984 are summarized in Table 2. Wave parameters include overall significant height, peak period, and direction. Height, period, and direction for sea and swell separately are also given. At 1200 EST the hindcast indicates the presence of short-period local wind seas of a 7-sec period and a 6.6-ft height propagating from approximately 200 deg coupled with swell of 12-13 sec period and 1.6-ft height propagating from about 92 deg. Thus, local wind seas were propagating toward the NNE and offshore swell was propagating toward the west. Since only the swell is propagating toward Barnegat, the relevant wave condition at Station 27 is a wave of approximately 12.5-sec period and 1.6 ft significant height, propagating from 90 deg. The hindcast wave spectrum indicates that significant wave energy was spread over the broad period range of 9-13 sec.

20. Additional perspective on wave conditions at the time of the accident is provided by the next hindcast grid point north of WIS Station 27 and by a gage at Manasquan, NJ, described in Part III of this report. The gage indicated 3.9 ft wave height and 8 to 11-sec period at 1200 EST, 10 November 1984. The hindcast grid point, which coincides with WIS Station 23, indicated 2.6-ft wave height, 7.7-sec period, and 167-deg direction for swells.

21. Based upon consideration of the hindcasts and the gage data, the following wave condition was selected for input to the nearshore wave propagation and shoaling model: significant height 2.6 ft (0.8 m), period 11-sec, direction 92 deg.

Nearshore Wave Propagation and Shoaling

22. The numerical model used for nearshore wave propagation and shoaling differs significantly from the model used for offshore wave growth and propagation. The nearshore model was selected because it is well-documented and has been used on numerous projects (Ebersole, et al 1985). Its accuracy is quite suitable for engineering studies. The model is based on the concept of a wave train with uniform wave height and period moving in a single direction with no spread. The concept is appropriate for the swell waves to be modeled.

23. The nearshore wave model employs an iterative, finite-difference calculation scheme including both refraction and diffraction effects produced by an irregular sea bottom. Formal assumptions on which the model equations are based are: gentle bottom slopes, monochromatic and linear waves, negligible energy reflection, negligible energy loss due to bottom friction or wave breaking outside the surf zone, negligible wave and current interaction, and negligible energy input from the wind. The model has been extended, verified, and successfully used for engineering studies beyond the range of the formal assumptions in shallow coastal areas, including areas of wave breaking. Since the accident occurred outside the jetties and the waves are expected to approach from a direction nearly parallel to the jetties, it is appropriate to use a model which omits the complexities of wave reflection and transmission by the jetties.

24. The nearshore model operates on a grid which is superimposed upon the study area. A grid extending about 20 n miles in the offshore (X) direction and about 11 n miles in the alongshore (Y) direction was used in this study. The Y-axis orientation was chosen parallel to the general trend of the shoreline adjacent to Barnegat Inlet. The grid cell size is smallest in the vicinity of Barnegat Inlet and increases with distance offshore. This feature

allows relatively detailed resolution in the area of greatest interest and coarse resolution in the offshore areas. The grid boundaries are shown in Figure 5. Grid cells at the entrance to Barnegat Inlet are 800 ft on a side. The seaward boundary of the grid was chosen such that WIS Station 27 coincides with one of the grid points.

25. A bottom depth was determined for each of the grid cells as a basic input to the model. The source of depth data for most of the grid was National Oceanic and Atmospheric Administration nautical chart Nu. 12323 (April 1983). A coarser version of the grid compatible with the spatial resolution of depths on the NOAA chart was overlaid on the chart and depth values were estimated. The depths were entered into a computer program for grid interpolation to provide depths at all cells on the computational grid. A constant factor of 0.6 ft was added to each depth to correct to the actual water level at the time of the accident. The correction is discussed in the section on Waves Modified by Ebb Tidal Current.

26. Depths in the immediate vicinity of Barnegat (delineated in Figure 1) were taken from detailed soundings rather than the NOAA chart. The soundings were collected in July and August 1984 by NAP. They represent the most accurate available representation of the bottom depths in and around Barnegat Inlet at the time of the accident. The soundings indicate a large shoal seaward of the South jetty and a smaller shoal seaward of the tip of the North jetty. Soundings from other recent years were reviewed. Although the shoals change configuration, they are a reasonably persistent feature in most of the recent records. Seaward shoals are typical of both natural and jettied tidal inlets (Figure 2) and have been historically documented at Barnegat (Fields 1984). Evidence of wave breaking on shoals is given in aerial photographs taken 8 October 1984 (Figure 6). The shoals are a natural consequence of the significant northerly and southerly longshore currents at Barnegat described by Ashley et al (1986). Therefore the shoals were represented in the model grid.

27. The soundings are given with much finer spatial resolution than the model grid. A visual averaging procedure was used to assign a representative depth to each grid cell. Sounding depths were reported with reference

to the National Geodetic Vertical Datum (NGVD). They were converted to the Mean Low Water datum used on the NOAA chart by subtracting 2.0 ft from each value and corrected to actual water level by adding 0.6 ft.

28. Wave conditions were input to the nearshore propagation and shoaling model along its seaward boundary. The primary input is the wave condition determined from the offshore model and available measurements as described in the previous section. The sensitivity of the model to variations in the input wave condition was also investigated by running with a range of values as follows: wave height - 2.3, 2.6, 3.3, and 3.9 ft; wave direction - 62, 72, 82, 92, 102, 112, 122, and 132 deg true north. A total of 32 wave conditions were run.

29. Results from the nearshore wave model are given in Appendix A for the grid points near the inlet entrance as shown in Figure 1. Both the offshore input and nearshore output wave conditions are given. The length of the wave in the shallow depth is also given. The wavelength represents the horizontal distance between two successive wave crests, measured parallel to the direction of wave motion. Wavelength as well as wave height is relevant to navigation because it is indicative of wave steepness and horizontal scale of the waves, which can be compared with boat dimensions.

30. The nearshore propagation and shoaling process generally causes an increase in wave height at this site. For the higher input wave conditions at the shallower grid points, wave breaking occurs and the wave height is lower than the input wave height. For some wave directions at some points, the waves must transit a shallow seaward bar. If the bar is sufficiently shallow to induce breaking, the wave heights shoreward of the bar are taken as 0.5 times the local water depth in accordance with experimental evidence. This effect is particularly evident at Point A. Wave directions tend to become perpendicular to the orientation of the bottom contours, which varies somewhat between grid points summarized in Appendix A. In general, wavelength decreases with water depth.

31. The grid points which are believed to most nearly match the site of the accident are Points C and G. The offshore wave condition estimated from the offshore wave model and measurements is a wave height of 2.6 ft, period of 11 sec and direction of 92 deg true north. The corresponding nearshore wave conditions are wave height of 4.3 ft and 4.0 ft and direction of 80 deg and

91 deg for Points C and G respectively, with period unchanged. As indicated in Appendix A, the result is relatively insensitive to small changes in offshore wave direction unless breaking is induced but varies significantly with significant changes in offshore wave height.

Waves Modified by Ebb Tidal Current

32. The nearshore wave propagation and shoaling model discussed in the previous section does not incorporate any influence of nearshore currents on the waves. Currents are potentially a major consideration at the entrance to a tidal inlet such as Barnegat. Thus a special task in this study was to investigate local currents at Barnegat and to assess their effect on waves at the entrance at the time of the accident.

33. The effect of currents on waves can be likened to the effect of the movement of a police car on the pitch of its siren. A person hears a high pitched siren when the police car is moving toward him and a low pitched sound when the car is moving away. In this case the change in pitch is obvious and dramatic to a person standing near the route of a fast-moving police car. In much the same way, when water waves encounter an opposing current, the wave height will increase and the wavelength will become shorter. The changes result in steeper waves which may cause difficulties for navigation, particularly for small boats. The phenomenon of wave modification by currents is routinely experienced in most inlet areas with a significant tide range.

34. Ebb currents through inlets are a natural consequence of the earth's astronomical tide. As the tide level in the ocean rises, water flows through the inlets into the sound and back bay areas. The increase in water level for areas inside the inlet may be greater or less than for the ocean. However the areal extent of the bay is typically quite large and a significant quantity of ocean water must be injected through the inlet or inlets which feed it. This situation often results in strong inlet currents as a large volume of water passes through the narrow inlet throat during the 6-hour interval between low and high tide.

35. Similarly, as the ocean tide level falls, a strong seaward flow develops in the inlets. The falling tide, or ebb tide, is usually of much more concern than the rising, or flood, tide for navigation purposes. Wave

conditions approaching the inlet from the ocean side are nearly always higher than from the back side. Thus the hazardous situation of high waves encountering an opposing current is fairly common during ebb tide at exposed ocean inlets.

36. Since the winds at Barnegat Inlet on 10 November 1984 prior to the accident were not severe, tide conditions may be attributed entirely to the astronomical tides. These tides can be predicted with high accuracy at many sites where tide gages have been operated. The tide tables published by the National Ocean Service (1984b) include a station on Barnegat Bay designated as Barnegat Inlet. This station is relatively distant from the open ocean and is not precisely representative of the open coast tides. A truly open coast station at Atlantic City, NJ, and two other stations considered reasonably representative of the open coast (Sandy Hook and Manasquan Inlet) indicate that high and low tides at the Barnegat Inlet station occur at nearly the same time as on the open coast but have a mean range of 3.1 ft rather than about 4.1 ft.

37. The published tide table gives a predicted high tide at Barnegat at 0800 EST on 10 November and a low tide at 1443 EST. The elevation difference between high and low tide at the reference station Sandy Hook is 5.2 ft. This range is 13 percent higher than the mean range at Sandy Hook, indicating a spring tide event. The 4.1-ft mean range estimated for Barnegat open coast, incremented by 13 percent, gives an estimate of 4.6 ft for the tide range between 0800 and 1443 EST, 10 November 1984.

38. The accident occurred at 1230 EST, that is 2 hours and 13 minutes before low tide. The tide level at that time for Barnegat open coast is predicted as 1.2 ft above low water. The tidal elevation is estimated as 1.0 ft above MLW. The accident occurred during a time of ebb current in a relatively large tide range. The effect of the current on wave conditions must be considered.

39. Measurements of currents in Barnegat Inlet at the time of the accident are not available. The tidal currents were estimated using information from a short-term measurement program at Barnegat during March 1980 (PRC Harris 1980). The PRC Harris report includes plotted curves of measured tidal elevation and

current at one cross section of the inlet during a complete tidal cycle (Figures 7 and 8). The measurements show that tide elevation and current fluctuations are nearly in phase, that is the maximum velocities occur very near to the times of high and low tide elevation. The curve in Figure 8 was used to estimate tidal current at the time of the accident. The velocity 2 hours and 13 min before low tide was estimated and then adjusted to account for the difference in tidal range between the day of PRC Harris' measurements and the day of the accident. The current at 1230 EST on 10 November 1984 was estimated as 2.2 ft/sec. The estimates provided by this procedure are quite approximate because the measurements were taken at a different location within the inlet from where the accident occurred and with somewhat different channel and shoal configurations than existed when the accident occurred. Nonetheless, the estimates provide a useful perspective on the effect of currents.

40. To assess the range of possible ebb current speeds at Barnegat, published tidal current tables (National Ocean Service 1984a) were also reviewed. The tables indicate the maximum ebb current may reach speeds of 4.2 ft/sec (2.5 knots). For this condition, the current speed at a time 2 hours and 13 minutes before low tide would be about 2.6 ft/sec. Currents as high as 11.8 ft/sec (7 knots) have been reported in Barnegat Inlet (National Ocean Service 1984c).

41. The wave direction at the entrance to Barnegat at the time of the accident was found earlier to be in the approximate range of 120 deg to 160 deg. The orientation of the entrance channel is about 140 deg. Thus the waves were moving in a direction nearly opposite to the current. It is consistent with other approximations in the investigation of currents to treat the waves and currents as moving in directly opposing directions. Thus a relatively simple wave and current interaction model can be used. It should also be noted that the current speeds discussed in the preceding paragraphs apply in the main channel; the speeds outside the channel would be expected to be lower.

42. The effect of inlet current on incoming waves at the time of the accident was estimated with a model by Herchenroder (1981) based on theory given by Peregrine and Jonsson (1983). Calculations were made for current

speeds of 2.1, 2.2, 2.6, 3.0, 3.3, and 3.4 ft/sec and for water depths characteristic of the 8 summary grid points in Figure 1 (Appendix B). Results are given in terms of ratios of wave length, and wave height. Each ratio represents the wave parameter (e.g. wave height) in the presence of current and shallow water divided by the parameter in shallow water with no current.

43. The cases in Appendix B which best match the circumstances of the accident are for a period of 11 sec, current of 2.2 ft/sec, and depth of 6 and 7 ft, Points C and G respectively. The wavelength and height ratios are 0.83 and 1.01 (Point C) and 0.84 and 1.01 (Point G), respectively. The final estimate of wave conditions at the time of the accident is derived from the ratios as

For Point C

Wave height = 1.01 x 4.3 ft = 4.3 ft

Wave direction = 80 deg

Wavelength = 0.83 x 151 ft = 125 ft

For Point G

Wave height = 1.01 x 4.0 ft = 4.0 ft

Wave direction = 91 deg

Wavelength = 0.84 x 164 ft = 138 ft

44. The results of the hindcast represent what is customarily called the significant wave conditions, that is the height and period represent the average parameters of the one-third highest waves. Waves in the ocean actually have a wide variety of heights and periods. The statistical distribution of heights of individual waves in a sea state has been widely studied. It is reasonably well-documented and consistent over a wide range of conditions and it is generally fit by a Rayleigh distribution function. Individual waves higher than the significant height are not unusual. In some cases waves much higher than the significant height occur though the probability of such events is low. Based on the Rayleigh distribution, approximately one wave out of every 1000 waves can be expected to be twice as high as the significant wave. This guidance generally has been found to apply even when the waves are high and depths are shallow such that the higher waves begin to break.

PART III: COMPARISON WITH AVAILABLE MEASUREMENTS

NOAA Buoy

45. In conjunction with the hindcasting effort described in Part II, CERC obtained and reviewed data from two measurement sites in the vicinity of Barnegat Inlet. Both sources were accelerometer buoys, one a NOAA buoy located offshore of northern New Jersey and the other a Corps of Engineers buoy located nearshore at Manasquan, New Jersey.

46. NOAA buoy 44008 was located 220 nautical miles east of Barnegat Inlet in deep water at 40°30'N, 69°23'49"W (Figure 5). CERC obtained a computer tape of data from the month of November 1984. The data show significant wave heights ranging from 3.9 ft to 6.2 ft on 10 November (Table 3). Peak spectral wave periods on the same days were generally about 3 to 5 sec but a 9.1-sec peak period was reported near the time of the accident.

47. The variations in peak period bear further discussion. Most of the time wave conditions at any point in the ocean represent a combination of wave trains which have been generated in various parts of the ocean. The waves have directions and periods determined by the circumstances of their generation and propagation. The peak energy density associated with each wave train and, to a lesser extent, the peak period and direction are statistically variable quantities. In any comparison of wave periods, considerable variability can be expected. It is common in multiple wave train sea states to find a different dominant peak at two nearby sites, between two estimates at the same site by different methods (e.g., acceleromater buoy and hindcast), and even between two successive estimates at the same site. The same peaks typically appear in each estimate but the relative magnitude of the peaks is a statistically variable quantity. The 9.1-sec peak period which appears in the NOAA buoy record for 10 November 1984 is indicative of a swell wave train which is overshadowed by shorter period wave trains in other records.

48. The wave hindcast results for a location near NOAA buoy 44008 for the day of the accident, indicates significant heights of 4.3 ft to 5.9 ft and peak periods ranging from 5.9 s to 9.1 s (Table 4). The hindcast heights compare well with the buoy measurements. The hindcast peak periods are longer

than the buoy values in most cases. Swell tends to be more dominant in the hindcast than in the buoy measurements though the swell is also evident in the buoy spectra.

Corps of Engineers Buoy at Manasquan

49. A small accelerometer buoy was operational at a site about 4500 ft offshore and 2100 ft upcoast from Manasquan Inlet (Figure 5). The water depth at the gage was 50 ft. Manasquan is approximately 20 nm north of Barnegat Inlet. The gage was operated by CERC as part of the Monitoring of Completed Coastal Projects effort.

50. Waves at the time of the accident at Barnegat were generated by a large scale weather system relatively distant from shore. In this circumstance, the offshore wave conditions for Barnegat and Manasquan would be expected to be very similar. This expectation is supported by CERC's offshore wave hindcast which shows little variation in wave conditions over this section of coast. Thus for 10 November 1984, the measurements at Manasquan are helpful in assessing wave conditions at Barnegat.

51. Measurements at Manasquan on 10 November are summarized in Table 5. The significant wave height at 1200 EST is 3.9 ft and the peak spectral period is 8.8 sec. The significant height at this gage and also at the NOAA buoy represent an energy-based estimate which is comparable to the hindcast wave height parameters for the water depths they represent.

52. The complete energy spectrum from the Manasquan gage at 1200 EST is given in Table 6. The spectrum indicates a strong concentration of wave energy at periods ranging from 8.8 to 10.9 sec. The longer periods in this range are consistent with the hindcast at Barnegat. Significant wave heights at Manasquan and Barnegat should not be directly compared because heights are highly influenced by local bathymetry.

PART IV: COMPARISON WITH GENERAL WAVE CLIMATE

53. Wave conditions at the time of the accident can be put in historical perspective by comparing them with the general wave climate around Barnegat Inlet. The best source of wave climate data for the area is the WIS hindcasts, which cover the 20-year period 1956-75.

54. The selection of data sets for comparison must be done carefully. The hindcasts at Barnegat are highly influenced by local shoals and are not appropriate for direct comparison with the WIS data set. The measurements at Manasquan were taken further offshore in an area upcoast from the inlet and are expected to be considerably less affected by irregular bottom conditions. Thus the Manasquan measurements can be compared with WIS Phase III Station 57 data summaries (Figure 5), which are derived by assuming straight parallel bottom contours over a 10-mile stretch of coast.

55. The Manasquan data were collected in 50-ft depth and WIS Station 57 represents 33-ft depth. The depth difference could induce some change in wave conditions. A simple spectral numerical model (US Army Corps of Engineers 1985) was used to route the Manasquan wave height to 33-ft depth, assuming the wave approached perpendicular to shore. The transformed wave height decreased from 3.9 ft to 2.6 ft. The model assumes straight parallel bottom contours and locally generated wave conditions. Since the latter assumption is not satisfied by wave conditions on 10 November 1984, it is expected that the transformed Manasquan wave height is overly attenuated and the actual transformed wave height should be between 2.6 and 3.9 ft.

56. Data summaries for WIS Station 57 were obtained from Appendix C of Jensen (1983). The summaries include mean H_s by month and year (Table 7), largest H_s by month and year (Table 8), joint distribution table of H_s and peak period for the full 20 years (Table 9), and wave rose for the full 20 years (Figure 9). The symbol H_s is used to denote significant wave height.

57. Parameters of interest for comparison with the transformed Manasquan data were extracted from the WIS summaries (Figure 10). The parameters include average H_s for all November's in the 20-year period (0.5 m or 1.6 ft), average H_s during the entire 20 years, all months (0.5 m or 1.6 ft), highest H_s in any November during the 20-year period (3.1 m or 10.2 ft), and highest H_s during the entire 20 years, all months (4.0 m or 13.1 ft).

58. Because of the uncertainties in the transformed data, Manasquan results are plotted in Figure 10 as a range of values. The plots indicate that wave conditions on 10 November 1984 were higher than average for the time of year. The Manasquan wave height was 1.0-2.3 ft (0.3-0.7 m) higher than the November mean. The Manasquan heights were not an extreme condition as they are 2-3 ft lower than the highest H_s for most Novembers'.

59. Probability estimates for the 10 November wave condition can be extracted from Table 9. The appropriate intervals for the transformed Manasquan data are 0.5-0.99 m for height and 8.0-8.9 sec for period. Waves with this height/period combination may be expected 4 percent of the time. Waves of 0.5-0.99 m height, regardless of period, occurred 26 percent of the time. The probabilities for the untransformed Manasquan wave height of 3.9 ft (1.2 m) are lower, 1.1 percent for the height/period combination and 7.4 percent for all periods. If a longer wave period is considered, such as 10.0-10.9 sec, the probabilities shift to lower values but in no cases less than one percent.

60. An assessment of the severity of the offshore waves near the time of the accident can be made by comparing the results from the offshore hindcast with wave data summaries for WIS, Phase II Station 27 (Tables 10-12). The location of Station 27 is shown in Figure 5. One of the offshore hindcast points coincided with Station 27. The results at this point at 1200 EST 10 November 1984 are significant wave height of 6.6 ft (2.0 m), peak spectral period of 7.1 sec. It was noted earlier that this wave condition included a dominant sea propagating toward the north-northeast and a secondary swell propagating toward the west.

61. The WIS Station 27 summaries indicate an average H_s of 4.6 ft (1.4 m) for all Novembers'. The highest H_s in any one November ranged from 8.5 ft to 18.7 ft (2.6 m to 5.7 m). Table 12 also indicates that the wave condition was above average for the months of October through December, but was not an extreme condition. A graphical comparison is given in Figure 11.

62. The wave climate comparison is summarized in Table 13. The conclusion is that significant wave conditions on 10 November 1984 had higher heights and longer periods than the average for November but neither height nor period was a rare extreme with very low probability of occurrence.

PART V: SUMMARY AND CONCLUSIONS

63. Swell waves arriving at Barnegat Inlet at the time of the accident were generated by a high pressure weather system centered 800nm to the northeast. The pressure gradients appear to have been intensified by the presence of Hurricane Klaus located further south and moving in a north-easterly direction. Wind fields around the time of the accident were recreated and used to drive a numerical wave hindcasting model covering the western portion of the north Atlantic Ocean. The output from the model and available gage data were used to estimate significant wave height, period, and direction at a point offshore from Barnegat Inlet. The offshore wave condition was used to drive a nearshore propagation and shoaling model.

64. The accident occurred during a part of the month in which the tidal fluctuations were higher than average. The accident coincided with a time of strong ebb tidal flow through Barnegat Inlet. A procedure was developed whereby wave heights and wavelengths from the nearshore model can be adjusted for the effect of currents.

65. The hindcasts were compared with available measurements from two gages. Hindcasts and gages were found to be generally consistent in identifying and characterizing the swell waves of interest at Barnegat.

66. Wave conditions at 1200 EST, 10 November 1984, were compared to the general wave climate to assess the severity of the event at Barnegat Inlet. The conclusion was that both significant wave height and period were higher/longer than average for the season, but neither height nor period nor the height/period combination were highly unusual extreme events.

67. Information on wave conditions at Barnegat Inlet at the time of the accident is summarized in Table 14. The observed wave heights are variable as would be expected for visual estimates from a moving boat. However, the hindcasts are consistent with the general sense of the observations.

68. Both hindcasts and observations for the time of the accident indicate Barnegat Inlet was experiencing moderately intense wave conditions. There was a high degree of spatial variability. Waves were breaking in some areas and not in others. Offshore waves were reported as noticeably lower than waves in the inlet.

69. The waves at the accident site were a result of a number of processes, induced primarily by the shallow bottom. The accident site is in the vicinity of a shoal seaward of the monument on the end of the North jetty. Waves moving into shallow water such as the shoal area generally increase in height and decrease in wavelength. These changes steepen the wave significantly as it approaches breaking. The wave shape changes as well. The crest in shallow water becomes narrow and spiked. Thus, the impact of a wave crest in shallow water can be much more noticeable than a crest of the same height in deeper water. Wave steepening can be further accentuated by refraction induced by the crescentic shoal which typically forms seaward of an inlet and by ebb currents emanating from the inlet. All of the processes were active at Barnegat Inlet at the time of the accident.

70. Most of the discussion in this report deals with significant wave height and significant or peak wave period. The heights and periods of individual waves in the ocean can vary considerably from the significant values. Waves with height higher than the significant height are common. The statistical distribution of wave heights in the ocean is well documented. For example, the distribution predicts that one wave out of every 1,000 waves will have a height approximately twice the significant height. The probability may change in the presence of strong currents or strong breaking.

71. The wave which caused the accident was described as 8 to 10 ft in height in the deposition of Mr. Allan L. Duchesneau. The data in Table 14 strongly indicates that this wave was higher than the significant wave height at the time. Given significant wave heights on the order of 4 ft at Barnegat Inlet at the time, a single wave 8 to 10 ft high would be a possible but rare event.

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Table 1

Observed Wave Conditions at Barnegat Inlet Near the Time of the Accident

Source	Wave Height (ft)	Wave Direction	Remarks
Coast Guard rescue personnel	6-8, with occasional 10		
Newspaper account	4-5		Asbury Park Press, 11 and 12 November 84
Coast Guard log	4-5		Breaking on bar in inlet
	3-4		Outside inlet
Survivor's deposition	1-1.5 8-10 for single wave hitting boat	Toward the west	Allan Louis Duchesneau

Table 2

Hindcasts for 10 November 1987 for WIS Station 27, Including Significant Wave Height (H_s), Peak Wave Period (T_p), Mean Wave Direction D, Wind Speed, and Wind Direction

				SEA			SWELL			WIND	
Time (EST)	H_s (ft)	T_p (s)	D (deg)	H_s (ft)	T_p (s)	D (deg)	H_s (ft)	T_p (s)	D (deg)	Speed (knots)	Dir. (deg)
0000	4.3	11.1	90	3.6	4.6	205	2.3	11.1	87.	15	205
0100	4.6	4.8	95	3.9	4.8	205	2.3	11.1	89.	16	205
0200	4.6	5.0	101	4.3	5.0	205	2.3	12.5	90.	16	205
0300	4.9	5.2	110	4.6	5.2	205	2.0	12.5	90.	17	205
0400	5.6	5.9	123	4.9	5.4	205	2.0	12.5	90.	18	205
0500	5.6	5.9	135	5.2	5.6	205	2.0	12.5	88.	18	210
0600	5.9	5.8	160	5.6	5.8	205	2.0	12.5	89.	19	210
0700	6.2	5.9	171	5.9	6.0	206	2.0	12.5	91.	20	210
0800	6.2	6.2	178	5.9	6.3	206	1.6	12.5	91.	20	210
0900	6.2	6.7	184	5.9	6.5	206	1.6	12.5	93.	20	210
1000	6.6	6.7	186	6.2	6.7	206	1.6	12.5	91.	20	210
1100	6.6	6.7	191	6.2	6.9	206	1.6	12.5	92.	20	210
1200	6.6	7.1	194	6.6	7.1	205	1.6	12.5	93.	20	210
1300	6.9	7.1	196	6.6	7.3	205	1.3	12.5	94.	20	210
1400	6.9	7.7	197	6.9	7.6	204	1.3	12.5	93.	20	210
1500	7.2	7.1	198	6.9	7.8	203	1.3	12.5	95.	20	210
1600	7.2	7.7	198	6.9	7.9	202	1.3	12.5	98.	20	210
1700	7.5	7.7	197	7.5	8.2	201	1.3	12.5	102.	21	210
1800	7.5	8.3	197	7.5	8.3	201	1.0	12.5	93.	21	210
1900	7.5	7.7	196	7.5	8.4	200	1.0	12.5	102.	21	210
2000	7.5	7.7	196	7.5	8.4	199	1.0	12.5	96.	21	210
2100	7.5	7.7	195	7.5	8.4	198	1.0	12.5	94.	21	210
2200	8.2	8.3	195	8.2	8.7	197	1.0	12.5	114.	22	205
2300	8.2	8.3	194	8.2	8.8	196	0.0	0.0	0.	22	205

Table 3

Wave Parameters from NOAA Buoy 44008, 10 November 1984

Time (EST)	H_s (ft)	T_p (s)
00	3.9	4.8
01	3.9	5.9
02	3.9	5.0
03	4.3	5.0
04	4.3	6.7
05	4.3	3.1
06	4.6	9.1
07	3.9	7.7
08	4.3	2.9
09	4.9	3.1
10	4.9	3.3
11	4.6	3.3
12	4.9	3.7
13	4.6	3.6
14	4.9	4.0
15	4.9	3.8
16	4.9	4.3
17	4.9	4.8
18	5.2	4.5
19	5.6	4.8
20	5.6	4.8
21	5.9	5.0
22	5.9	4.5
23	6.2	5.0

Table 4
Wave Parameters for hindcast location
near NOAA buoy 44008
10 November 1984

Time (EST)	H_s (ft)	Tp (s)
00	4.3	9.1
01	4.3	9.1
02	4.3	9.1
03	4.3	9.1
04	4.6	9.1
05	4.6	9.1
06	4.6	9.1
07	4.6	9.1
08	4.9	9.1
09	4.9	9.1
10	4.9	8.3
11	5.2	8.3
12	5.2	8.3
13	5.6	8.3
14	5.6	8.3
15	5.6	8.3
16	5.6	5.9
17	5.6	5.9
18	5.9	6.2
19	5.9	6.7
20	5.9	6.7
21	5.6	6.7
22	5.6	6.2
23	5.6	6.2

Table 5
Wave Parameters at Manasquan, NJ, 10 November 1984

Time (EST)	H_s (ft)	T_p (s)
0600	4.6	9.8
1000	3.9	10.9
1200	3.9	8.8
1400	4.6	10.9
1700	5.6	10.9
1800	6.2	*
2000	5.6	*
2359	4.9	4.8

* Results for indicated times failed to pass quality control checks.

Table 6

Wave Energy Spectrum at Manasquan, NJ, 1200 EST 10 November 1984.

Period (sec)	Energy (%)	
16.8	.2	
14.2	1.4	
12.3	4.5	
10.9	7.0	(secondary peak)
9.8	6.5	
8.8	9.6	(primary peak)
8.1	5.9	
7.4	3.2	
6.9	3.7	
6.4	3.3	
6.0	5.8	
5.6	5.6	
5.3	5.1	
5.0	4.4	
4.8	2.5	
4.5	1.4	
0-4.3	30.0	

Table 7

Mean Significant Wave Height (in meters)
by Month and Year, WIS Station 57

	MONTH												
YEAR	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC	MEAN
1956	1.0	0.7	0.5	0.5	0.3	0.4	0.5	0.4	0.6	1.2	0.7	0.4	0.6
1957	0.3	0.7	0.6	0.4	0.3	0.5	0.3	0.4	0.5	0.8	0.6	0.7	0.5
1958	0.4	0.3	0.6	0.7	0.6	0.5	0.3	0.5	0.3	0.9	0.5	0.4	0.5
1959	0.4	0.4	0.4	0.6	0.2	0.2	0.4	0.4	0.4	0.8	0.6	0.4	0.4
1960	0.3	0.7	0.5	0.5	0.5	0.9	0.6	0.5	0.6	0.5	0.4	0.2	0.5
1961	0.4	0.6	0.5	0.5	0.5	0.6	0.4	0.4	0.7	0.8	0.6	0.3	0.5
1962	0.5	0.6	1.4	1.1	0.4	0.4	0.3	0.4	0.4	0.4	0.9	0.7	0.6
1963	0.4	0.5	0.5	0.3	0.6	0.4	0.2	0.2	0.8	0.5	0.6	0.3	0.4
1964	0.6	0.5	0.5	0.7	0.9	0.5	0.5	0.3	0.8	0.5	0.3	0.5	0.5
1965	0.5	0.5	0.3	0.4	0.3	0.5	0.4	0.4	0.5	0.4	0.4	0.3	0.4
1966	0.4	0.3	0.4	0.5	0.5	0.6	0.4	0.3	0.6	0.4	0.5	0.4	0.4
1967	0.3	0.6	0.7	0.3	0.4	0.3	0.4	0.6	0.9	0.5	0.3	0.5	0.5
1968	0.4	0.4	0.5	0.5	0.6	0.6	0.5	0.5	0.5	0.3	0.5	0.4	0.5
1969	0.7	0.9	0.9	0.6	0.4	0.4	0.4	0.3	0.5	0.5	0.6	0.5	0.6
1970	0.2	0.8	0.5	0.7	0.5	0.3	0.4	0.3	0.4	0.8	0.9	0.4	0.5
1971	0.3	0.6	0.5	0.4	0.6	0.4	0.4	0.5	0.6	1.0	0.5	0.5	0.5
1972	0.4	0.6	0.7	0.3	0.8	0.6	0.2	0.3	0.6	0.6	0.6	0.6	0.5
1973	0.4	0.8	0.9	0.5	0.6	0.4	0.3	0.3	0.3	0.5	0.4	0.8	0.5
1974	0.5	0.6	0.6	0.6	0.4	0.6	0.4	0.5	0.4	0.2	0.4	0.6	0.5
1975	0.6	0.5	0.6	0.4	0.3	0.5	0.8	0.5	0.4	0.5	0.4	0.7	0.5
MEAN	0.5	0.6	0.6	0.5	0.5	0.5	0.4	0.4	0.5	0.6	0.5	0.5	

Table 8

Largest Significant Wave Height (in meters)
by Month and Year, WIS Station 57

	MONTH											
YEAR	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC
1956	3.6	2.0	2.4	2.3	1.1	1.1	1.5	1.2	4.0	2.8	2.1	2.0
1957	1.7	2.1	2.7	2.3	1.4	1.5	1.0	1.8	1.9	3.3	2.3	2.2
1958	2.7	2.3	3.1	2.2	1.4	1.1	0.8	1.4	1.2	3.1	2.5	2.5
1959	2.2	2.1	2.4	2.1	0.8	1.1	2.1	1.7	1.1	2.6	1.9	1.7
1960	2.7	2.9	2.6	1.8	1.4	2.0	2.8	1.9	1.6	2.7	1.9	2.7
1961	2.9	3.5	2.7	2.7	2.7	1.7	1.3	1.2	2.5	2.1	2.2	1.7
1962	2.1	2.0	3.9	2.3	1.3	1.7	1.3	1.6	2.3	1.3	3.1	2.6
1963	2.1	2.5	2.1	2.1	2.3	2.4	1.3	1.9	2.5	2.4	2.3	2.0
1964	3.9	2.6	2.6	2.2	2.4	1.0	2.0	1.6	2.7	2.0	2.4	1.7
1965	2.9	2.6	2.0	1.7	1.0	1.9	1.1	1.4	1.5	2.2	1.5	2.0
1966	2.9	1.6	2.3	2.1	1.2	2.3	1.3	1.2	2.5	1.6	2.2	2.5
1967	1.4	2.3	2.5	1.4	2.2	0.9	1.1	1.3	2.7	1.6	1.4	2.9
1968	2.8	1.7	2.7	2.0	3.1	1.5	0.8	0.8	1.4	1.3	2.9	2.0
1969	3.2	2.8	2.5	1.6	1.6	1.1	1.7	1.0	2.2	2.2	3.0	3.0
1970	2.0	2.3	2.1	2.5	1.6	1.5	1.1	2.0	1.3	2.7	2.4	3.0
1971	2.0	2.4	2.7	3.3	2.4	1.5	1.3	2.7	1.7	2.5	2.6	1.9
1972	1.8	3.6	2.7	1.5	2.3	2.3	1.0	2.0	2.4	2.9	2.7	2.5
1973	2.6	2.8	2.3	2.6	2.2	1.8	1.0	1.5	2.1	3.2	2.0	3.6
1974	2.2	2.3	3.3	2.0	2.0	2.2	0.7	1.9	1.7	0.8	1.2	3.8
1975	2.9	2.6	3.3	2.0	1.1	2.4	2.7	0.9	2.2	2.1	2.9	3.3

LARGEST HS(METRES) FOR STATION 57 = 4.0

Table 9

Percent Occurrence(x100) of Significant Height and Period
For All Directions, WIS Station 57, 20 years,
Shoreline Angle = 12 Degrees Azimuth,
Water Depth = 10 Meters

HEIGHT(METRES)	PERIOD(SECONDS) 0.0-2.9	3.0-3.9	4.0-4.9	5.0-5.9	6.0-6.9	7.0-7.9	8.0-8.9	9.0-9.9	10.0-10.9	11.0-LONGER	TOTAL
0. - 0.49	438	938	572	421	581	1159	643	167	95	110	5124
0.50 - 0.99	.	255	732	281	128	450	405	155	61	102	2569
1.00 - 1.49	.	.	47	236	109	168	113	19	10	41	743
1.50 - 1.99	.	.	.	11	81	128	51	14	2	19	306
2.00 - 2.49	.	.	.	.	14	91	32	5	1	4	147
2.50 - 2.99	.	.	.	.	.	10	25	9	1	1	46
3.00 - 3.49	.	.	.	.	.	.	2	6	1	.	9
3.50 - 3.99	.	.	.	.	.	.	.	.	1	.	1
4.00 - 4.49	.	.	.	.	.	.	.	.	.	.	0
4.50 - 4.99	.	.	.	.	.	.	.	.	.	.	0
5.00 - GREATER	.	.	.	.	.	.	.	.	.	.	0
TOTAL	438	1193	1351	949	913	2006	1271	375	172	277	

AVE HS(M) = 0.51 LARGEST HS(M) = 3.97 TOTAL CASES = 58440

Table 10

Mean Significant Wave Height (in meters)
by Month and Year, WIS Station 27

YEAR	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC	MEAN
1956	2.2	1.4	1.3	1.2	0.8	0.7	1.0	0.8	1.0	1.7	1.3	1.1	1.2
1957	1.2	1.3	1.3	1.0	0.8	0.8	0.8	0.8	0.8	1.3	1.5	1.7	1.1
1958	1.5	1.5	1.6	1.4	0.9	0.9	0.9	0.9	0.8	1.5	1.3	1.4	1.2
1959	1.6	1.4	1.3	1.2	0.7	0.7	0.8	0.8	0.7	1.4	1.4	1.3	1.1
1960	1.3	2.0	1.6	1.2	0.8	1.3	0.9	0.9	0.9	1.1	1.1	1.3	1.2
1961	1.4	1.4	1.3	1.4	1.1	1.1	0.8	0.9	1.3	1.4	1.4	1.3	1.2
1962	1.4	1.3	2.3	1.5	0.7	0.7	0.8	0.8	0.9	1.1	2.1	1.9	1.3
1963	1.4	1.4	1.4	1.1	1.0	0.9	0.7	0.7	1.3	1.2	1.5	1.2	1.2
1964	1.9	1.7	1.4	1.2	1.2	0.8	0.9	0.7	1.3	1.0	1.1	1.5	1.2
1965	1.6	1.4	1.0	0.9	0.7	1.0	0.8	0.8	0.8	1.2	1.3	1.1	1.1
1966	1.7	1.0	0.9	0.8	0.8	1.1	0.8	0.8	1.1	1.0	1.2	1.5	1.1
1967	1.2	1.5	1.5	1.2	1.2	0.6	0.8	1.1	1.5	1.0	1.2	1.5	1.2
1968	1.3	1.5	1.4	1.1	0.9	0.8	0.6	0.7	0.6	0.8	1.4	1.6	1.1
1969	1.7	2.2	1.7	1.0	0.9	0.7	0.7	0.8	1.0	1.2	1.4	1.7	1.3
1970	1.4	1.7	1.2	1.3	0.9	0.8	0.7	0.8	0.8	1.3	1.3	1.4	1.1
1971	1.4	1.4	1.5	1.2	1.2	0.7	0.8	1.0	0.7	1.4	1.3	1.4	1.2
1972	1.4	1.8	1.6	1.1	1.2	1.0	0.7	0.7	1.1	1.3	1.7	1.5	1.3
1973	1.7	2.0	1.7	1.4	1.2	0.9	0.6	0.6	0.7	1.2	1.8	2.3	1.3
1974	1.2	1.9	1.7	1.5	0.9	0.8	0.8	0.7	0.7	0.9	1.4	1.5	1.2
1975	1.5	1.2	1.6	1.4	0.5	0.8	1.2	0.8	0.7	1.0	1.2	1.7	1.1
MEAN	1.5	1.5	1.5	1.2	0.9	0.9	0.8	0.8	0.9	1.2	1.4	1.5	

Table 11

Largest Significant Wave Height (in meters)
by Month and Year, WIS Station 27

YEAR	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC
	MONTH											
1956	5.6	3.9	4.1	4.2	2.4	2.1	2.9	3.4	5.2	4.3	3.6	3.4
1957	3.3	3.6	4.4	3.7	2.4	3.3	2.0	2.2	2.6	4.6	3.4	3.9
1958	3.9	3.4	5.1	4.1	2.9	2.0	2.5	2.8	3.0	4.5	4.2	4.5
1959	4.6	3.3	4.3	3.3	1.7	2.2	3.2	3.0	2.6	3.8	3.6	3.5
1960	3.7	5.4	3.9	3.1	1.9	3.2	4.2	3.0	2.1	4.2	2.6	4.3
1961	3.9	6.0	3.7	3.8	3.9	2.7	1.8	1.8	4.7	4.2	3.7	3.3
1962	4.0	3.4	7.2	4.5	1.8	2.2	2.1	2.3	3.7	3.2	4.9	4.8
1963	4.0	3.9	3.2	3.1	4.3	3.1	2.3	3.5	4.1	3.8	4.2	3.5
1964	6.2	3.9	4.0	3.1	3.2	2.4	3.3	3.1	3.8	2.9	3.5	3.9
1965	4.2	4.1	2.6	2.9	1.6	3.5	2.2	1.8	2.2	3.5	3.9	3.8
1966	5.3	3.3	3.0	2.7	3.0	3.2	2.2	2.9	3.3	3.6	3.6	4.1
1967	3.1	4.1	4.3	4.8	3.7	2.0	1.8	3.1	4.1	3.8	3.3	4.3
1968	3.9	4.4	4.3	3.3	4.0	1.6	1.2	1.3	1.8	3.1	4.4	5.0
1969	5.0	4.1	4.9	3.8	3.8	1.7	3.5	2.5	3.3	4.0	4.7	4.7
1970	3.8	4.1	3.5	5.0	1.9	2.9	2.1	3.3	3.1	4.2	3.8	5.1
1971	3.8	5.0	5.3	5.0	3.5	1.8	2.0	4.7	1.9	4.0	4.0	4.0
1972	3.7	6.1	4.3	3.3	3.4	3.4	2.5	3.3	3.7	4.4	4.7	4.2
1973	4.5	5.2	5.7	3.8	3.3	2.8	2.0	2.4	3.1	4.6	5.7	6.4
1974	3.5	5.5	5.5	4.2	3.4	3.2	1.6	3.1	3.1	3.3	4.4	6.1
1975	4.9	4.9	5.3	4.2	2.5	3.8	4.7	1.6	2.9	3.4	4.6	4.9

LARGEST HS(METRES) FOR STATION 27 = 7.2

Table 12

Percent Occurrence(X100) of Significant Height and Period
For All Directions, WIS Station 27, 20 Years,
October through December only

HS(METRES)	T(SECONDS) 0.0-2.9	3.0-4.9	5.0-6.9	7.0-8.9	9.0-10.9	11.0-12.9	13.0-14.9	15.0-LARGER	TOTAL
<0.5	517	576	31	109	57	12	.	.	1302
<1.0	.	2290	24	388	197	37	.	.	2936
<1.5	.	474	1415	232	50	15	.	.	2186
<2.0	.	.	1382	177	28	3	.	.	1590
<2.5	.	.	625	159	16	2	.	.	802
<3.0	.	.	150	345	12	.	.	.	507
<3.5	.	.	57	290	7	.	.	.	354
<4.0	.	.	10	148	9	.	.	.	167
<4.5	.	.	.	70	16	.	.	.	86
<5.0	.	.	.	16	18	.	.	.	34
5.0+	.	.	.	2	14	.	.	.	16
TOTAL	517	3340	3694	1936	424	69	0	0	

STATION 27 AVE HS(M)= 1.4 LARGEST HS(M)= 6.4 TOTAL CASES= 14720.

Table 13

Comparison of Wave Conditions at 1200 EST, 10 November 1984, with General Wave Climate

	Manasquan Buoy[1]	Offshore Hindcast[1]
Significant Height (ft)	2.6-3.9	6.6
Percent Exceedance[2]	38-13	20
Peak Period (S)	8.8-10.9	7.1
Percent Exceedance[2]	21-4	24

[1] Based on a 20-year data base from WIS Phase II, Station 57, for Manasquan and WIS Phase II, Station 27, for offshore hindcast.

[2] Percent exceedance is the percentage of values in the 20-year data base which are greater than or equal to the given value.

Table 14

Summary of Wave Conditions at Barnegat Inlet Around 1230 EST, 10 November 1984

Offshore Wave[1]		
Significant Height (ft)	Period (s)	Direction (deg)
2.6	11	92

Barnegat Inlet Waves

Source	Significant Height[3] (ft)	Period (S)	Direction (deg)	Length[3] (ft)	Depth (ft)
Hindcast:					
Point A	3.9	11	120	148	8
Point B	4.6	11	101	148	8
Point C[2]	4.3	11	80	125	6
Point D	2.8	11	65	230	18
Point E	3.6	11	118	113	5
Point F	4.1	11	99	138	7
Point G[2]	4.0	11	91	138	7
Point H	2.9	11	81	248	21
Observation:					
Coast Guard Log (breaking on bar)	4-5				
Coast Guard Log (outside inlet)	3-4				
Coast Guard Rescuer	6-8				
Survivor's (Duchesneau) Deposition	1-2		90		

[1] Best estimate to drive nearshore model.

[2] Points nearest the accident site.

[3] Includes effects of a 2.2 ft/sec (1.3 knot) current.

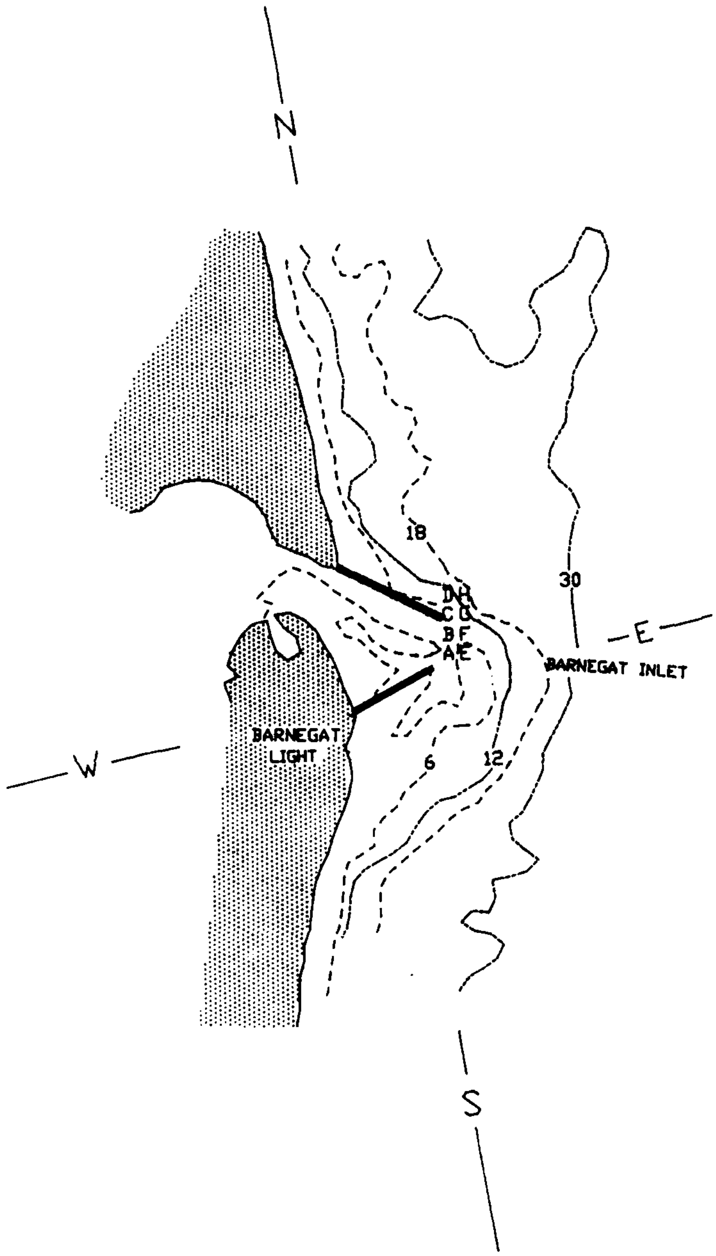


Figure 1. Bathymetry and hindcast points at Barnegat Inlet; depths are in feet

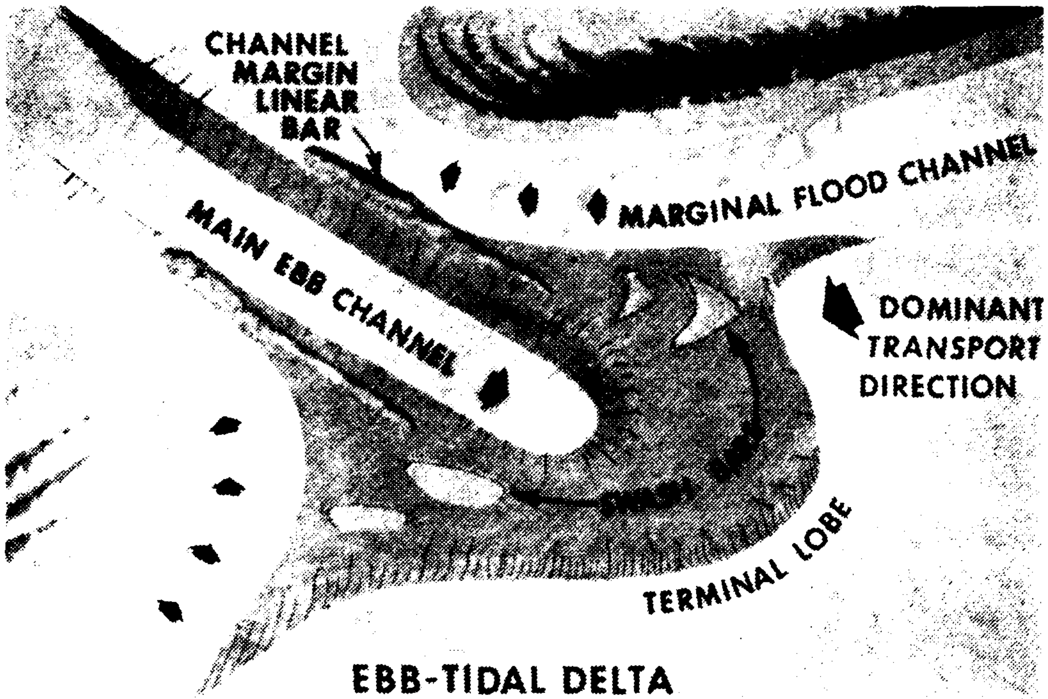


Figure 1. Typical features of a tidal inlet (from the Shore Protection Manual, after Hayes 1975)

Figure [illegible]. [illegible] entering an inlet through choppy waves ([illegible] 1977)

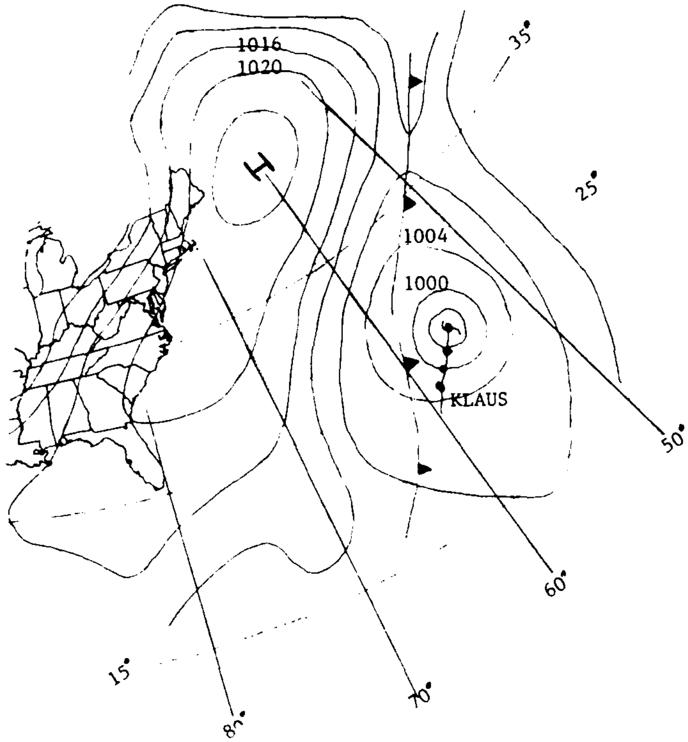


Figure 4. Weather map of the western North Atlantic Ocean at 0700 EST, 10 November 1984

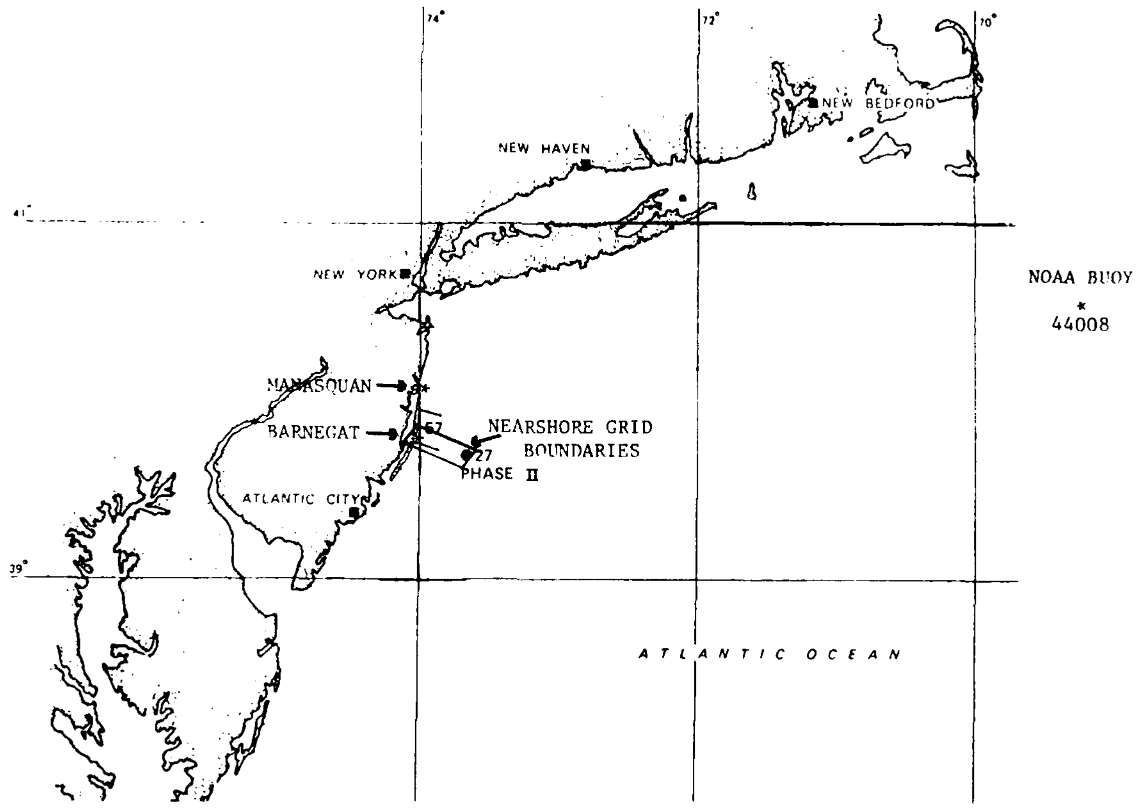
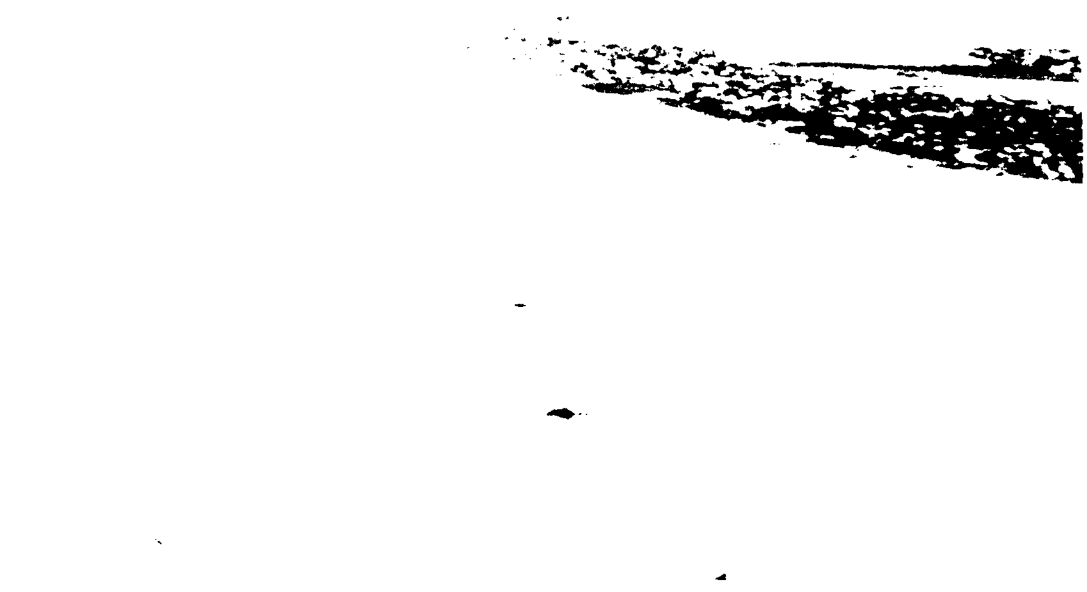
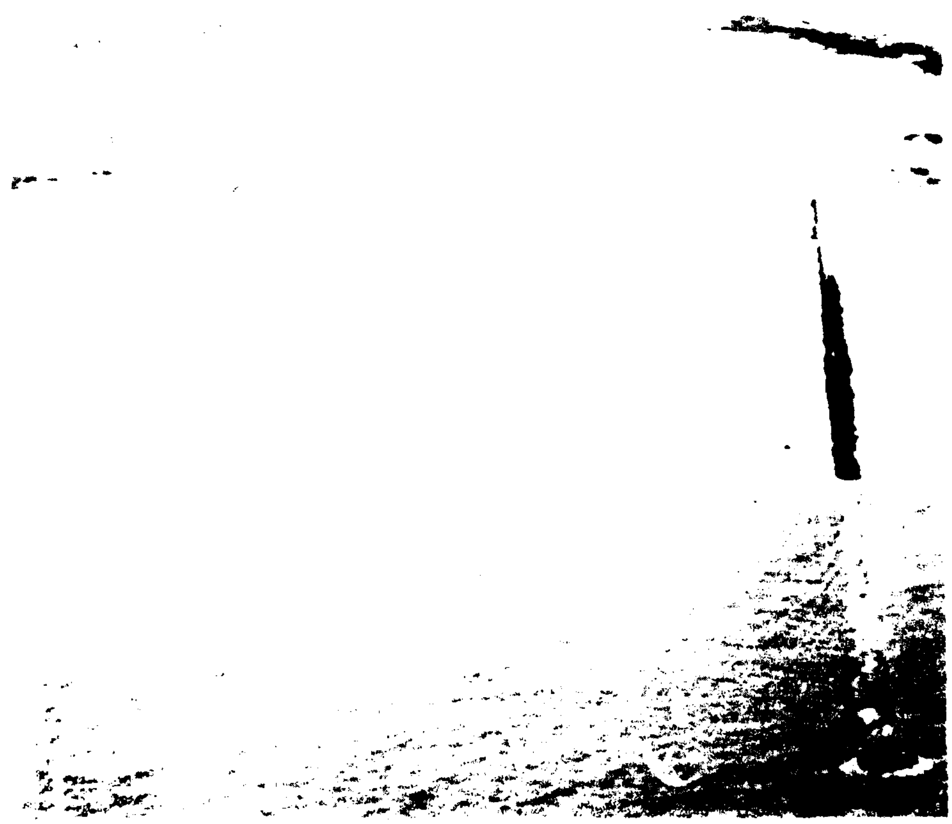


Figure 5. Location map



a.



b.

Figure [illegible]. Aerial [illegible] of [illegible] Inlet, [illegible] October 1980 [illegible]

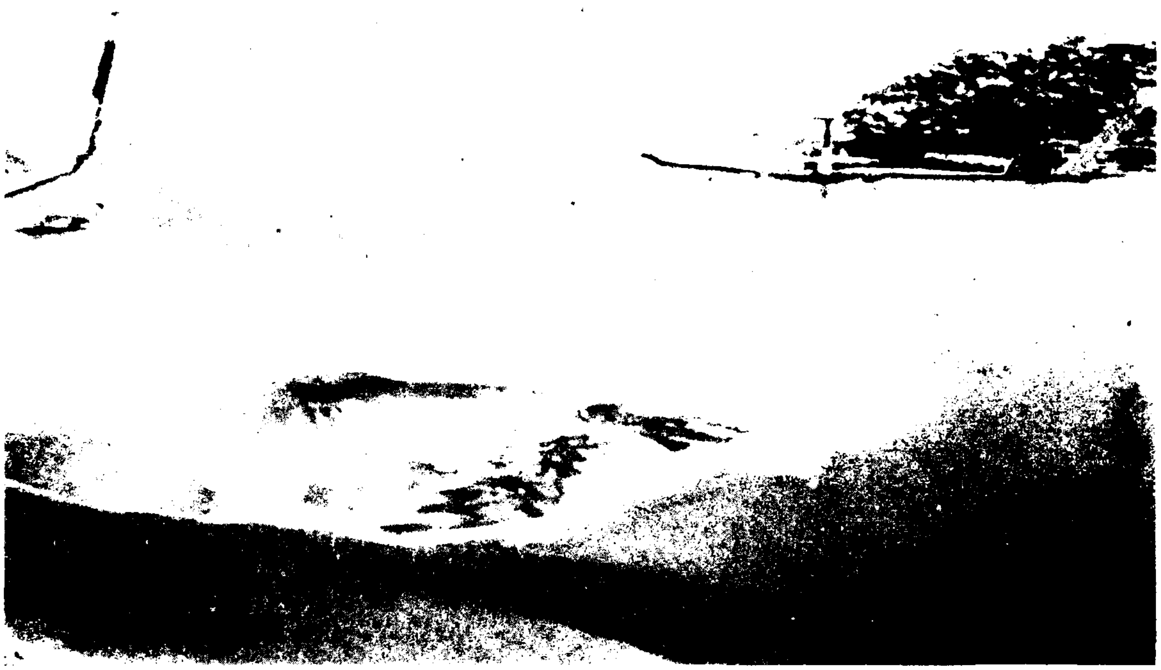


Figure 6. (Concluded)

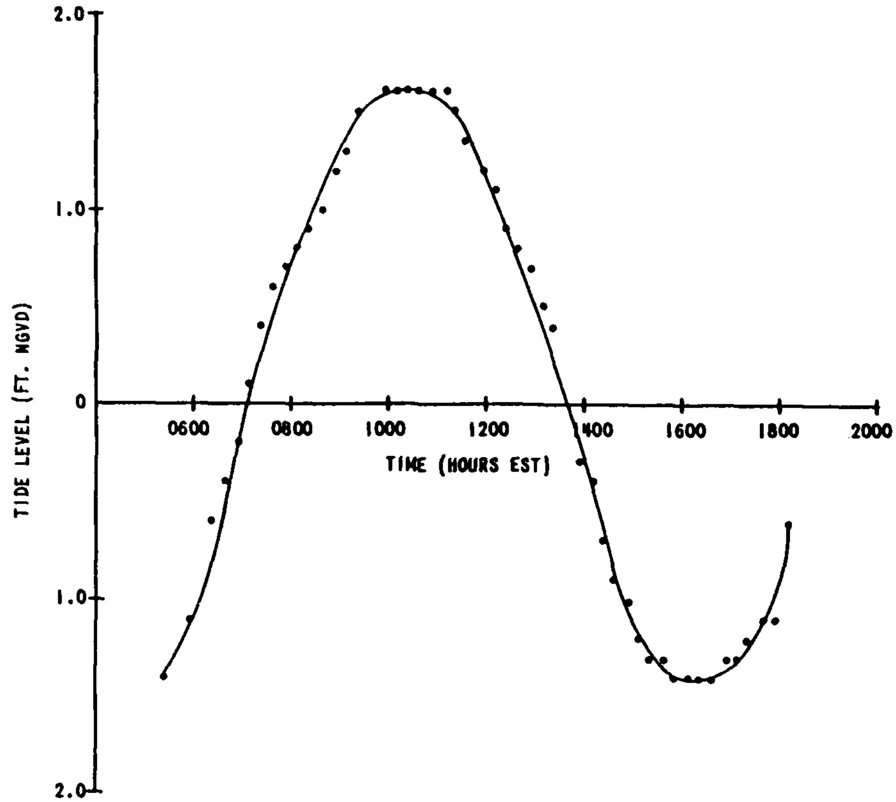


Figure 7. Measured tide level fluctuations, Barnegat Inlet, 20 March 1980 (from PRC Harris 1980)

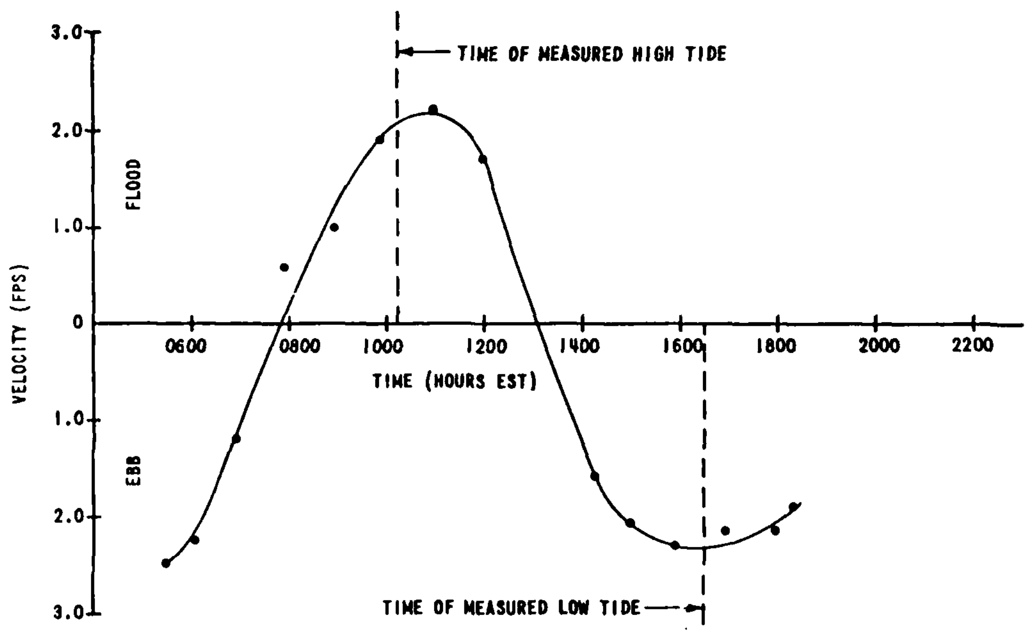


Figure 8. Average current velocity Barnegat Inlet, 20 March 1980 (from PRC Harris 1980)

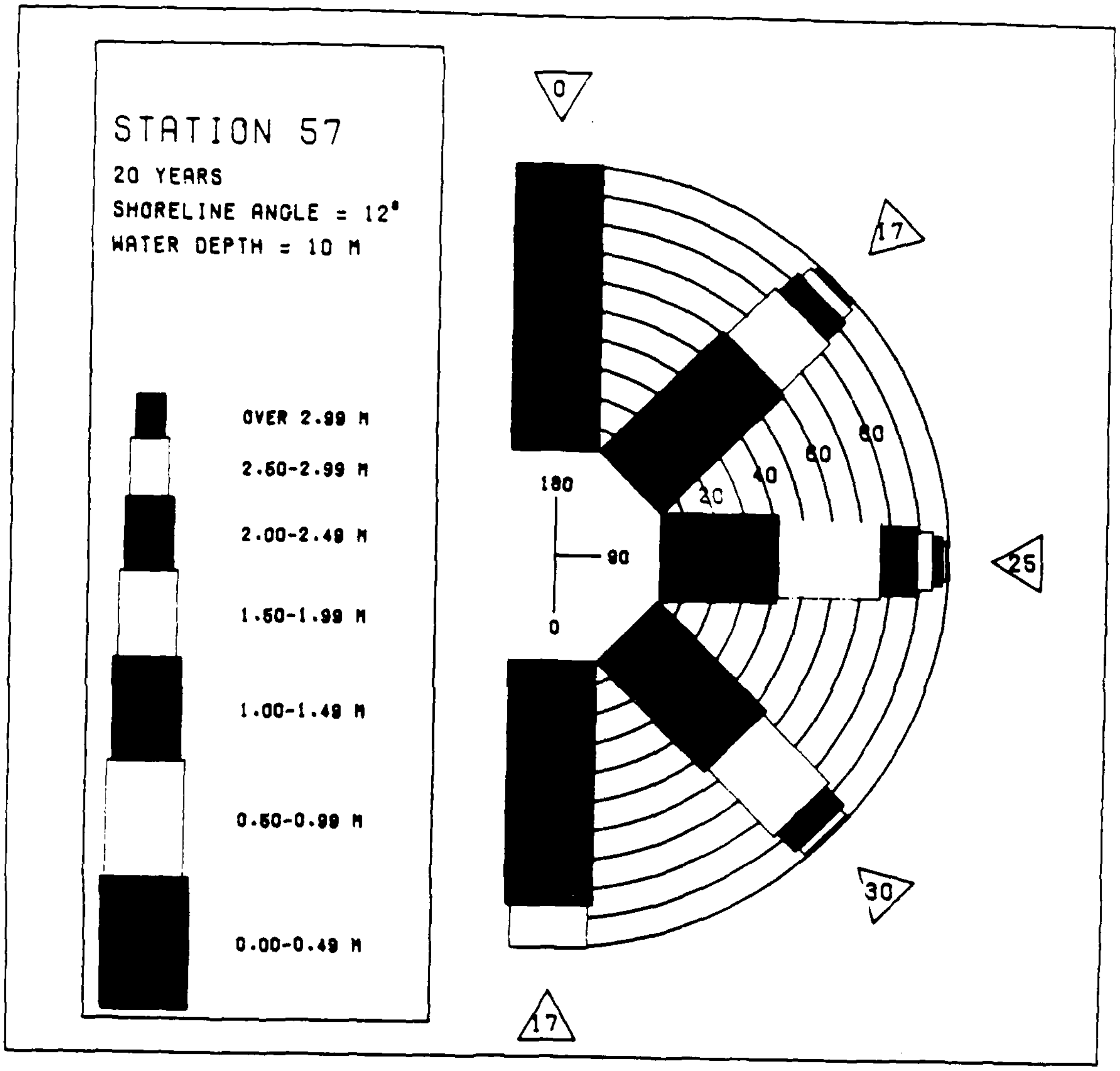


Figure 9. Wave rose, WIS Station 57

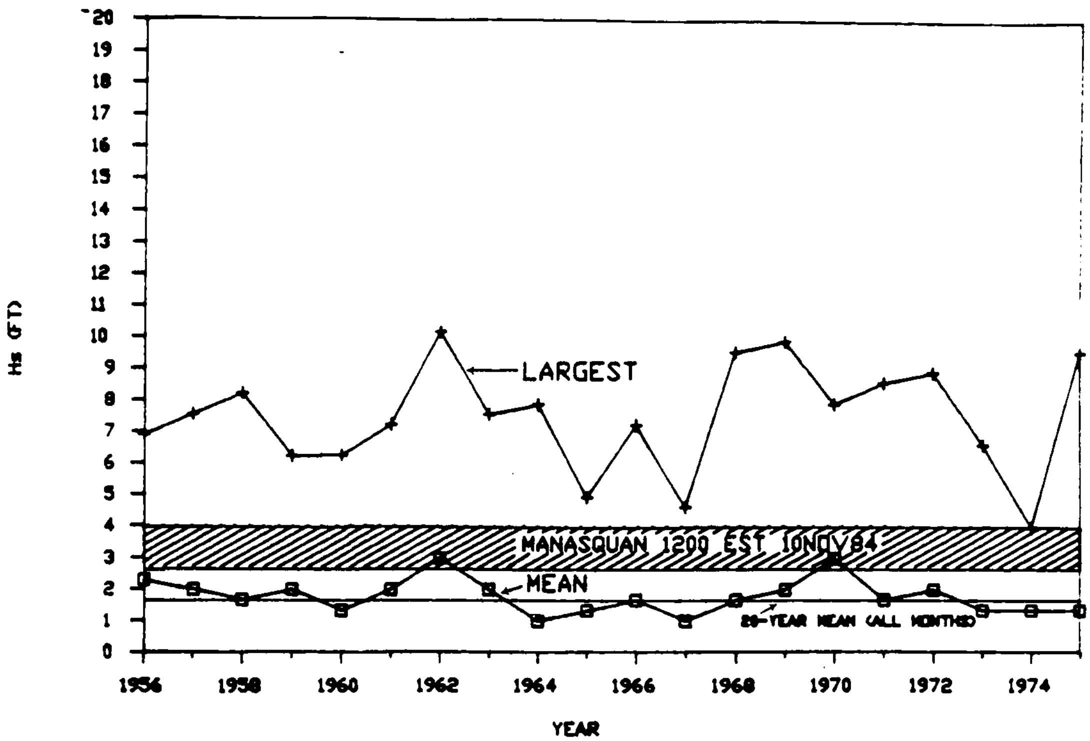


Figure 10. Comparison of Manasquan wave measurement on 10 November 1984 with general wave climate

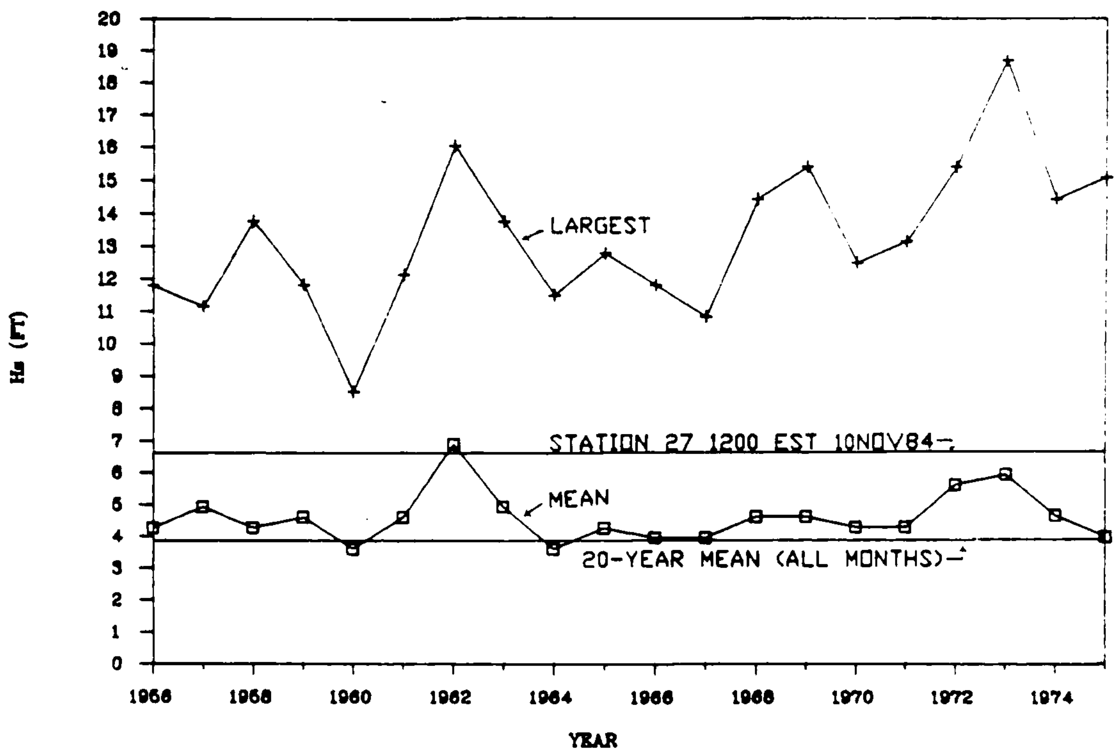


Figure 11. Comparison of wave hindcast at WIS Station 27 on 10 November 1984 with general wave climate

APPENDIX A: NEARSHORE WAVE RESULTS

Table A-1

Nearshore Wave Summaries for Barnegat Inlet, Point A, Water Depth 8 ft, Wave Period 11 Sec, Wavelength 174 ft

OFFSHORE		NEARSHORE	
Direction (deg)	Height (ft)	Direction (deg)	Height (ft)
132	2.3	137	3.8
122	2.3	133	3.8
112	2.3	128	3.8
102	2.3	124	3.8
92	2.3	120	3.8
82	2.3	116	3.8
72	2.3	112	3.8
62	2.3	108	3.4
132	2.6	137	3.8
122	2.6	133	3.8
112	2.6	128	3.8
102	2.6	124	3.8
92	2.6	120	3.8
82	2.6	116	3.8
72	2.6	112	3.8
62	2.6	108	3.8
132	3.3	137	3.3
122	3.3	133	3.8
112	3.3	128	3.3
102	3.3	124	3.8
92	3.3	120	3.8
82	3.3	116	3.8
72	3.3	112	3.8
62	3.3	108	3.8
132	3.9	137	3.8
122	3.9	133	3.8
112	3.9	128	3.8
102	3.9	124	3.8
92	3.9	120	3.8
82	3.9	116	3.8
72	3.9	112	3.8
62	3.9	108	3.8

Table A-2

<u>Nearshore Wave Summaries for Barnegat Inlet, Point B, Water Depth 8 ft, Wave Period 11 Sec, Wavelength 174 ft</u>

OFFSHORE		NEARSHORE	
Direction (deg)	Height (ft)	Direction (deg)	Height (ft)
132	2.3	121	4.0
122	2.3	116	4.1
112	2.3	111	4.1
102	2.3	106	4.1
92	2.3	101	4.0
82	2.3	97	3.9
72	2.3	92	3.8
62	2.3	89	3.5
132	2.6	121	4.4
122	2.6	116	4.5
112	2.6	111	4.5
102	2.6	106	4.5
92	2.6	101	4.5
82	2.6	97	4.4
72	2.6	92	4.3
62	2.6	89	4.0
132	3.3	121	5.2
122	3.3	116	5.2
112	3.3	111	5.3
102	3.3	106	3.8
92	3.3	101	5.2
82	3.3	97	5.1
72	3.3	92	5.0
62	3.3	89	4.8
132	3.9	121	3.8
122	3.9	116	3.3
112	3.9	111	3.8
102	3.9	106	3.8
92	3.9	101	3.8
82	3.9	97	3.8
72	3.9	92	3.8
62	3.9	89	3.8

Table A-3

Nearshore Wave Summaries for Barnegat Inlet, Point C, Water Depth 6 ft, Wave Period 11 Sec, Wavelength 151 ft

OFFSHORE		NEARSHORE	
Direction (deg)	Height (ft)	Direction (deg)	Height (ft)
132	2.3	94	4.0
122	2.3	90	4.1
112	2.3	87	4.1
102	2.3	83	4.1
92	2.3	80	4.0
82	2.3	77	3.8
72	2.3	74	3.6
62	2.3	71	3.4
132	2.6	94	4.3
122	2.6	90	4.3
112	2.6	87	4.3
102	2.6	83	4.3
92	2.6	80	4.3
82	2.6	77	4.3
72	2.6	74	4.2
62	2.6	71	3.9
132	3.3	94	4.3
122	3.3	90	4.3
112	3.3	87	4.3
102	3.3	83	4.3
92	3.3	80	4.3
82	3.3	77	4.3
72	3.3	74	4.3
62	3.3	71	4.3
132	3.9	94	4.3
122	3.9	90	4.3
112	3.9	87	4.3
102	3.9	83	4.3
92	3.9	80	4.3
82	3.9	77	4.3
72	3.9	74	4.3
62	3.9	71	4.3

Table A-4

Nearshore Wave Summaries for Barnegat Inlet, Point D, Water Depth 18 ft, Wave Period 11 Sec, Wavelength 256 ft

OFFSHORE		NEARSHORE	
Direction (deg)	Height (ft)	Direction (deg)	Height (ft)
132	2.3	77	2.2
122	2.3	74	2.2
112	2.3	71	2.3
102	2.3	68	2.3
92	2.3	65	2.3
82	2.3	62	2.2
72	2.3	59	2.2
62	2.3	56	2.1
132	2.6	77	2.5
122	2.6	74	2.6
112	2.6	71	2.7
102	2.6	68	2.7
92	2.6	65	2.7
82	2.6	62	2.6
72	2.6	59	2.5
62	2.6	56	2.4
132	3.3	77	3.3
122	3.3	74	3.5
112	3.3	71	3.6
102	3.3	68	3.6
92	3.3	65	3.7
82	3.3	62	3.6
72	3.3	59	3.5
62	3.3	56	3.3
132	3.9	77	4.0
122	3.9	74	4.2
112	3.9	71	4.4
102	3.9	68	4.5
92	3.9	65	4.5
82	3.9	62	4.5
72	3.9	59	4.4
62	3.9	56	4.2

Table A-5

Nearshore Wave Summaries for Barnegat Inlet, Point E, Water Depth 5 ft, Wave Period 11 Sec, Wavelength 138 ft

OFFSHORE		NEARSHORE	
Direction (deg)	Height (ft)	Direction (deg)	Height (ft)
132	2.3	130	3.6
122	2.3	127	3.6
112	2.3	124	3.6
102	2.3	121	3.6
92	2.3	118	3.6
82	2.3	115	3.6
72	2.3	113	3.6
62	2.3	111	3.4
132	2.6	130	3.6
122	2.6	127	3.6
112	2.6	124	3.6
102	2.6	121	3.6
92	2.6	118	3.6
82	2.6	115	3.6
72	2.6	113	3.6
62	2.6	111	3.6
132	3.3	130	3.6
122	3.3	127	3.6
112	3.3	124	3.6
102	3.3	121	3.6
92	3.3	118	3.6
82	3.3	115	3.6
72	3.3	113	3.6
62	3.3	111	3.6
132	3.9	130	3.6
122	3.9	127	3.6
112	3.9	124	3.6
102	3.9	121	3.6
92	3.9	118	3.6
82	3.9	115	3.6
72	3.9	113	3.6
62	3.9	111	3.6

Table A-6

Nearshore Wave Summaries for Barnegat Inlet, Point F, Water Depth 7 ft, Wave Period 11 Sec, Wavelength 164 ft

OFFSHORE		NEARSHORE	
Direction (deg)	Height (ft)	Direction (deg)	Height (ft)
132	2.3	112	3.5
122	2.3	109	3.6
112	2.3	106	3.7
102	2.3	102	3.7
92	2.3	99	3.6
82	2.3	96	3.5
72	2.3	93	3.4
62	2.3	90	3.2
132	2.6	112	4.0
122	2.6	109	4.1
112	2.6	106	4.1
102	2.6	102	4.2
92	2.6	99	4.1
82	2.6	96	4.0
72	2.6	93	3.9
62	2.6	90	3.6
132	3.3	112	4.9
122	3.3	109	5.0
112	3.3	106	5.1
102	3.3	102	5.1
92	3.3	99	5.1
82	3.3	96	5.0
72	3.3	93	4.8
62	3.3	90	4.5
132	3.9	112	5.1
122	3.9	109	5.1
112	3.9	109	5.1
102	3.9	102	5.1
92	3.9	99	5.1
82	3.9	96	5.1
72	3.9	93	5.1
62	3.9	90	5.1

Table A-7

Nearshore Wave Summaries for Barnegat Inlet, Point G, Water Depth 7ft, Wave Period 11 Sec, Wavelength 164 ft

OFFSHORE		NEARSHORE	
Direction (deg)	Height (ft)	Direction (deg)	Height (ft)
132	2.3	102	3.3
122	2.3	100	3.4
112	2.3	97	3.5
102	2.3	94	3.5
92	2.3	91	3.5
82	2.3	88	3.4
72	2.3	85	3.2
62	2.3	83	3.1
132	2.6	102	3.8
122	2.6	100	3.9
112	2.6	97	4.0
102	2.6	94	4.0
92	2.6	91	4.0
82	2.6	88	3.9
72	2.6	85	3.7
62	2.6	83	3.5
132	3.3	102	4.8
122	3.3	100	4.9
112	3.3	97	5.0
102	3.3	94	5.0
92	3.3	91	5.0
82	3.3	88	4.9
72	3.3	85	4.7
62	3.3	83	4.4
132	3.9	102	5.1
122	3.9	100	5.1
112	3.9	97	5.1
102	3.9	94	5.1
92	3.9	91	5.1
82	3.9	88	5.1
72	3.9	85	5.1
62	3.9	83	5.1

Table A-8

Nearshore Wave Summaries for Barnegat Inlet, Point H, Water Depth 21 ft, Wave Period 11 Sec, Wavelength 276 ft

OFFSHORE		NEARSHORE	
Direction (deg)	Height (ft)	Direction (deg)	Height (ft)
132	2.3	97	2.3
122	2.3	93	2.4
112	2.3	89	2.4
102	2.3	85	2.4
92	2.3	81	2.4
82	2.3	77	2.4
72	2.3	73	2.3
62	2.3	69	2.2
132	2.6	97	2.6
122	2.6	93	2.7
112	2.6	89	2.8
102	2.6	85	2.8
92	2.6	81	2.8
82	2.6	77	2.8
72	2.6	73	2.7
62	2.6	69	2.6
132	3.3	97	3.3
122	3.3	93	3.4
112	3.3	89	3.5
102	3.3	85	3.5
92	3.3	81	3.5
82	3.3	77	3.5
72	3.3	73	3.4
62	3.3	69	3.2
132	3.9	97	3.9
122	3.9	93	4.1
112	3.9	89	4.2
102	3.9	85	4.3
92	3.9	81	4.3
82	3.9	77	4.3
72	3.9	73	4.1
62	3.9	69	3.9

APPENDIX B: WAVE MODIFICATION BY CURRENTS

Table B-1

Modification by Ebb Current, Water Depth 5 Ft, Wave Period 11 Sec, Wavelength Without Current 138 ft

Current (ft/sec)	Length Ratio	Height Ratio
-2.1	.83	1.01
-2.2	.82	1.01
-2.6	.79	1.02
-3.0	.76	1.02
-3.3	.73	1.02
-3.4	.72	1.02

Table B-2

Modification by Ebb Current, Water Depth 6 Ft, Wave Period 11 Sec Wavelength Without Current 151 Ft

Current (ft/sec)	Length Ratio	Height Ratio
-2.1	.84	1.01
-2.2	.83	1.01
-2.6	.80	1.02
-3.0	.78	1.02
-3.3	.75	1.02
-3.4	.74	1.02

Table B-3

Wave Modification by Ebb Current, Water Depth 7 Ft, Wave Period 11 Sec, Wavelength Without Current 164 Ft

Current (ft/sec)	Length Ratio	Height Ratio
-2.1	.85	1.01
-2.2	.84	1.01
-2.6	.82	1.02
-3.0	.79	1.02
-3.3	.77	1.02
-3.4	.76	1.03

Table B-4

Wave Modification by Ebb Current, Water Depth 8 Ft, Wave Period 11 Sec, Wavelength Without Current 174 Ft

Current (ft/sec)	Length Ratio	Height Ratio
-2.1	.86	1.01
-2.2	.85	1.02
-2.6	.83	1.02
-3.0	.81	1.02
-3.3	.78	1.03
-3.4	.77	1.03

Table B-5

Wave Modification by Ebb Current, Water Depth 18 Ft, Wave Period 11 Sec, Wavelength Without Current 256 Ft

Current (ft/sec)	Length Ratio	Height Ratio
-2.1	.90	1.02
-2.2	.90	1.02
-2.6	.88	1.03
-3.0	.86	1.03
-3.3	.85	1.04
-3.4	.84	1.04

Table B-6

Wave Modification by Ebb Current, Water Depth 21 Ft, Wave Period 11 Sec, Wavelength Without Current 276 Ft

Current (ft/sec)	Length Ratio	Height Ratio
-2.1	.91	1.02
-2.2	.90	1.02
-2.6	.89	1.03
-3.0	.87	1.03
-3.3	.86	1.04
-3.4	.85	1.04

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